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WATER RESOURCES for EXPANDING WOOD-USING INDUSTRIES in NORTHEASTERN MINNESOTA

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FOREWORD

In recent years the northern Lake States area has felt increasing economic difficulty caused by curtailed employment in agriculture and mining. Unemployment has risen, and with it the need for developing additional economic opportunities within this area. One aid in strengthening the economy would be expanded markets for forest products. To help meet this need, the Station's marketing research program recently has been directed toward analyzing opportunities for increased manufacture and marketing of wood products from the forests of the northern Lake States.

Water, as well as the timber supply, frequently is a major factor governing expansion or development of certain wood-using industries. The following report on water resources is one of several which will analyze the timber resource and other factors related to market opportunities for wood products that could be manufactured in northeastern Minnesota. This report, based on data gathered from a number of sources, is not presented as original research on the part of Station personnel. It does assemble under one cover much general and specific information on those phases of water availability and use that would be sought by wood-using firms considering expansion or a new location in northeastern Minnesota. If, however, a firm should select one of the sites discussed here for serious consideration, many more details would be needed before a final decision could be made.

Because the report might be of interest to individuals with widely varying technical backgrounds, it is not presented in a highly technical format.

For assistance in assembling the information contained in this report, grateful acknowledgment is made to: the U.S. Geological Survey, St. Paul, Minn.; the Section of Water Pollution Control, Minnesota Department of Health; the Division of Waters and the Division of Game and Fish, Minnesota Department of Conservation; and Earl H. Ruble, Consulting Engineer, Duluth.

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INTRODUCTION

Some forest industries require large volumes of process water, while others need little or none. Those industries requiring insignificant volumes of water for manufacturing, such as sawmills, veneer mills, and charcoal plants, are not considered in this analysis. Water is generally not a limiting factor in choosing locations for such plants.

At the other extreme is the pulp and paper industry with large demands for process water. In 1950 these producers required about 4 percent of the total estimated industrial withdrawal of water in the United States.[1/] By 1959 the percentage had risen to 16, or 1,937 billion gallons yearly, a phenomenal increase from about 1,150 billion gallons in 1950.[2/] The importance of water to future development of the industry is found in the following statement of John G. Strange, President of the Institute of Paper Chemistry at Appleton, Wis.

> "...taking all aspects into account, therefore, it can be said that the paper industry is more critically dependent on water, and especially high quality water, than the balance of industry. It is apparent that this dependency will have a more restrictive influence on future expansion than any other single economic or raw material factor.[3/]

Water, of varying qualities, is essential for washing pulpwood, woodpulp, and the pulp handling machines; as process water for cooking wood chips to make pulp; as a medium for heat transfer; and as a vehicle for transporting the constituents of paper in the paper machines. Only a small fraction of the water is consumed in manufacturing.

This report is concerned with site selection for minimum economic-size pulp and composition-board mills, especially as related to their water requirements.

GENERAL WATER REQUIREMENTS--VOLUME AND QUALITY

As indicated in table 1, demand for water varies significantly by process and product. Small volumes are necessary for hardboard manufacturing, while a 100-ton bleached sulfite plant uses at least 5 million gallons per day.

1/ Mussey, Orville D. Water requirements of the pulp and paper industry. U.S. Geol. Survey Water Supply Paper 1330-A, 71 pp. 1961.

2/ U.S. Bureau of the Census. Industrial water use. 1958 Census of Manufacturers, 115 pp. 1961.

3/ Statement taken from an opening address at a Pulp, Paper, and Paperboard Industrial Waste Conference in Chicago, Dec. 1-2, 1959.

NOTE: The author, James Blyth, is a Research Forester employed at the Station's Marketing Project in Duluth, Minn.

Table 1.--Minimum process water requirement estimates for minimum economic-size pulp and composition-board mills

Process	24-hour capacity (tons)	Minimum required flow		5 day BOD[2] for effluent at 20° C (lbs./ton)
		Thousand gal./day	CFS[1]	
Groundwood	50	500[3]	.77	8
Semichemical, unbleached	50	NA[3]	NA	125
Sulphate, bleached	150	9,000	13.89	75
Sulphate, unbleached	250	7,500	11.58	60
Cold soda	50	NA	NA	75
Sulfite, bleached	100	5,000	7.72	NA
Sulfite, unbleached	100	3,000	4.63	415
Hardboard:				
Wet form, batch process	20	50	.08	NA
Wet form, continuous process	30	300	.46	NA
Dry form	50	(4)	(4)	(4)
Insulation board	175	1,400	2.20	NA
Particle board	5/ 8,500	(4)	(4)	(4)

Sources: U. S. Forest Service, Wisconsin State Committee on Water Pollution, Robert A. Taft Sanitary Engineering Center, U. S. Public Health Center.

1/ Cubic feet per second.
2/ Biochemical oxygen demand.
3/ NA = not available.
4/ Negligible.
5/ Square feet.

Chemical and physical characteristics of water can affect production costs and product quality in many of the mill types found in table 1. For example, turbidity in water causes a loss of brightness and darkens the color of white or tinted paper. Color, due to natural organic material or industrial waste and sewage, may be absorbed by cellulose fibers, or it may cause a loss of brightness in a white- or light-colored finished paper. Hardness of water, caused by magnesium and calcium compounds, may be responsible for scale forming on the screens, Fourdrinier wire, condensers, recirculating systems, and pumps of pulp and paper mills.

Results of a 1951 study of raw (untreated) water used in pulp and paper manufacturing are shown in table 2. Minimum, median, and maximum

Table 2.--Chemical and physical characteristics of untreated water used in pulp and paper manufacture

(Ppm except for color, pH, and temperature)

Constituent or property	No. of samples	Minimum	Median	Maximum
Silica as SiO_2	51	1.0	6	56
Iron (Fe)	42	0	.05	2.6
Hardness as $CaCO_3$				
Total	56	0	55	475
Noncarbonate	7	0	22	150
Alkalinity as $CaCO_3$	24	(1/)	28	180
Color (units)	29	2	12	360
Turbidity as ppm SiO_2	12	(2/)	4	55
Dissolved solids	42	18	140	1,080
pH	49	4.6	7.2	9.4
Average temperature (°F)	52	51	58	89
Chloride (Cl)	58	0	6	165
Free carbon dioxide (CO_2)	9	0	3.5	23
Sodium (Na)	24	(2/)	6	225
Sulfate (SO_4)	59	0	18	366
Fluoride (F)	14	0	.2	2.2
Nitrate (NO_3)	32	0	.3	8.1
Aluminum (Al)	15	0	.5	11.2

Source: Mussey, Orville D. Water requirements of the pulp and paper industry. U. S. Geol. Survey Water Supply Paper 1330-A, 1955 (Results of a survey in 1951).

1/ Acidity 17 ppm. 2/ Trace.

values in parts per million (ppm) for several important chemical constituents and physical properties are reported, based upon samples of water collected. Table 3 gives specifications for chemical composition of process water for manufacturing various pulps and papers. These two tables will be used as guides in determining the desirability of water in northeastern Minnesota for pulp and paper operations.

Pollution problems can develop in pulp and paper operations where the process water must be returned to a river or lake, the water of which ultimately is used for other purposes. The effluent or waste discharged from mills into streams or other bodies of water affects the character and quality of the water receiving it. Problems associated with waste discharges include removal of dissolved oxygen, fiber bottom deposits,

toxicities to fish and fish foods, tastes and odors, color, foaming, and stimulation of bacterial growths. Without proper control, such changes as may occur in streams or lakes can have detrimental effects on current or future uses.

Table 3.--Specifications for chemical composition of process water for manufacture of various pulps and papers

Constituent or property	Maximum allowed in ppm by product				
	Soda and sulfate pulp	Groundwood paper	Kraft paper: Bleached	Kraft paper: Unbleached	Fine paper
Turbidity	1/ 25	1/ 50	40	100	10
Color (units)	5	30	25	100	5
Total hardness as $CaCO_3$	100	200	100	200	100
Calcium hardness as $CaCO_3$	50	-	-	-	50
Magnesium hardness as $CaCO_3$	50	-	-	-	-
Alkalinity as $CaCO_3$	75	150	75	150	75
Iron (Fe)	.1	.3	.2	1.0	.1
Manganese (Mn)	.05	.1	.1	.5	.05
Silica (SiO_2)	20	50	50	100	20
Dissolved solids	250	500	300	500	200
Free carbon dioxide as CO_2	10	10	10	10	10
Chloride (Cl)	75	75	200	200	-
Residual chlorine as CI_2	-	-	-	-	2.0

Source: Tentative standards established by the Technical Association of the Pulp and Paper Industry as listed in Mussey, Orville D. Water requirements of the pulp and paper industry. U. S. Geol. Survey Water Supply Paper 1330-A, 1955.

1/ Materials causing turbidity must not be gritty.

The most important characteristic of mill effluents from a pollution point of view is their oxygen demand or ability to extract dissolved oxygen biochemically from dilution water, assuming the suspended solids have been effectively removed. The degree of pollution is usually measured by the 5-day biochemical oxygen demand (BOD). This determination measures the amount of oxygen consumed by mill effluent and is usually reported in pounds of oxygen required per ton of air-dried product.

Table 1 indicates the 5-day BOD expected from effluents of minimum economic-size plants producing various pulps. These plants are assumed to be of average modern design. The pollution strength of effluents varies with process designs and the degree of waste treatment. If there is sufficient dilution water in the receiving stream to assure an adequate supply of oxygen at all times for aquatic life propagation, then the water generally is suitable for other uses. The only apparent exceptions might be

taste and odor problems for a drinking water supply obtained a short distance downstream and the possible development of esthetically objectionable slime growths.[4/]

STUDY AREA AND PRESENT WATER USE

The Arrowhead area of northeastern Minnesota--Pine, Carlton, St. Louis, Lake, and Cook Counties--is a land of numerous lakes and streams and has more than 140 miles of shoreline on Lake Superior (fig. 1). The six watershed units--St. Louis River, Lake Superior, Rainy Lake, Kettle River, Snake River, and St. Croix River--found in the five-county study area are shown in figures 2-7.[5/] Although the total supply of surface water is large, sites for forest industry are limited by the dispersal of the water volume among numerous small streams and lakes.

Recreational use of water is important in the study area (fig. 8). Large numbers of fishermen, campers, canoeists, and sightseers visit the region each year. Summer homes and resorts dot the shorelines of many lakes and streams. The Boundary Waters Canoe Area of the Superior National Forest has been set aside for semi-wilderness canoeing, camping, and outdoor recreation. In this area commercial or industrial development is prohibited, but supervised timber cutting is allowed in all but a fairly narrow strip along the international border and major water routes.

The majority of the communities obtain their water from wells sunk in glacial drift or in the Biwabik Iron Formation (table 4). Hibbing and Virginia use water from abandoned mines for part of their supplies, but Hibbing is shifting gradually to wells. Most communities have at least primary sewage treatment facilities, which indicates that the study area should be relatively free of municipal waste pollution.

Industrial water use has steadily increased in the Mesabi Range area of St. Louis County to meet the expanding requirements of beneficiating low-grade iron ores. The construction of a taconite-processing plant near Aurora involved the development of a water supply from the Partridge River. Large volumes of surface water in the St. Louis River watershed are utilized for hydroelectric power for municipal and industrial purposes. There are five such reservoirs between Cloquet and Fond du Lac. The St. Louis River supplies all of the process water required by wood-using industries at Cloquet (fig. 9). Cities and villages utilizing water at steam-gener-

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4/ U.S. Public Health Service and Missouri Water Pollution Board. Effluent disposal considerations in possible pulp and paper mill developments in southeastern Missouri. 101 pp. 1960.

5/ The maps in figures 2-7 were drafted by the Cartographic Laboratory, Department of Geography, University of Minnesota, and were based on maps prepared in 1959 by the Division of Waters, Minnesota Department of Conservation.

Table 4.--Municipal water supplies and sewage treatment facilities within study areas

Municipality	1960 population	No. of wells	Water source	Approximate average use (gpd)[1]	Water treatment	Sewage treatment[2]
Askov	331	2	Hinckley Formation	*30,000	Yes	NS
Aurora	2,799	2	Glacial drift and Biwabik Iron Formation	250,000	Yes	S
Babbitt	2,587	2	Glacial outwash	200,000	Yes	S
Barnum	417	1	Glacial drift	*40,000	Yes	S
Beaver Bay	287	0	Lake Superior	41,000	Yes	NS
Biwabik	1,836	2	Biwabik Iron Formation	250,000	Yes	S
Buhl	1,526	2	Biwabik Iron Formation	125,000	No	S
Carlton	862	2	Glacial drift	65,000	Yes	P
Chisholm	7,144	2	Glacial outwash and mine shaft in Biwabik Iron Fm.	480,000	Yes	S
Cloquet	9,013	6	Glacial drift	772,600	Yes	P
Duluth	106,884	0	Lake Superior	16,000,000	Yes	P
Ely	5,438	0	Burntside Lake	600,000	Yes	S
Eveleth	5,721	0	St. Marys Lake	700,000	Yes	S
Floodwood	677	2	Glacial drift	55,000	No	NT
Gilbert	2,591	2	Glacial drift	184,000	Yes	S
Grand Marais	1,301	0	Lake Superior	148,000	Yes	P
Hibbing	17,731	12	Glacial drift	2,414,000	No	S
		1	Biwabik Iron Formation		Yes	
Hinckley	851	1	Hinckley Formation	*75,000	No	NT
Hoyt Lakes	3,186	0	Colby Lake	240,000	Yes	S
Iron Junction	187	1	Virginia Slate	10,000	No	NT
Kettle River	234	1	Glacial drift	*40,000	Yes	P
Kinney	240	1	Glacial outwash	60,000	Yes	P
McKinley	408	1	Biwabik Iron Formation	18,000	No	P
Mahoning	*100	2	Biwabik Iron Formation	35,000	No	P
		1	Pokegama Quartzite			
Meadowlands	176	2	Glacial outwash	10,000	No	ST
Moose Lake	1,514	2	Glacial drift	*90,000	No	P
Mountain Iron	1,808	2	Glacial outwash	100,000	No	S
Orr	361	1	Pre-Cambrian granite	*30,000	Yes	S
Pine City	1,972	3	Glacial drift	*150,000	Yes	S
Sandstone	1,552	1	Hinckley Formation	*100,000	No	S
Scanlon	1,126	0	Uses Cloquet system	--	Yes	P
Silver Bay	3,723	0	Lake Superior	500,000	Yes	S
Taconite Harbor	*200	3	Keweenawan lava flows	16,000	Yes	P
Tower-Soudan (Breitung Township)	1,755	3	Glacial drift	400,000	Yes	S
Two Harbors	4,695	0	Lake Superior	1,414,000	Yes	P
Virginia	14,034	1	Biwabik Iron Formation & mine shaft in Iron Fm.	2,280,000	Yes	S

Sources: Minnesota Department of Conservation, Division of Waters.
Minnesota Department of Health, Division of Environmental Sanitation.
U. S. Geoglogical Survey.

1/ Gallons per day.
2/ P = primary, S = secondary, NS = no system, NT = no treatment, ST = septic tank.
* Estimated.

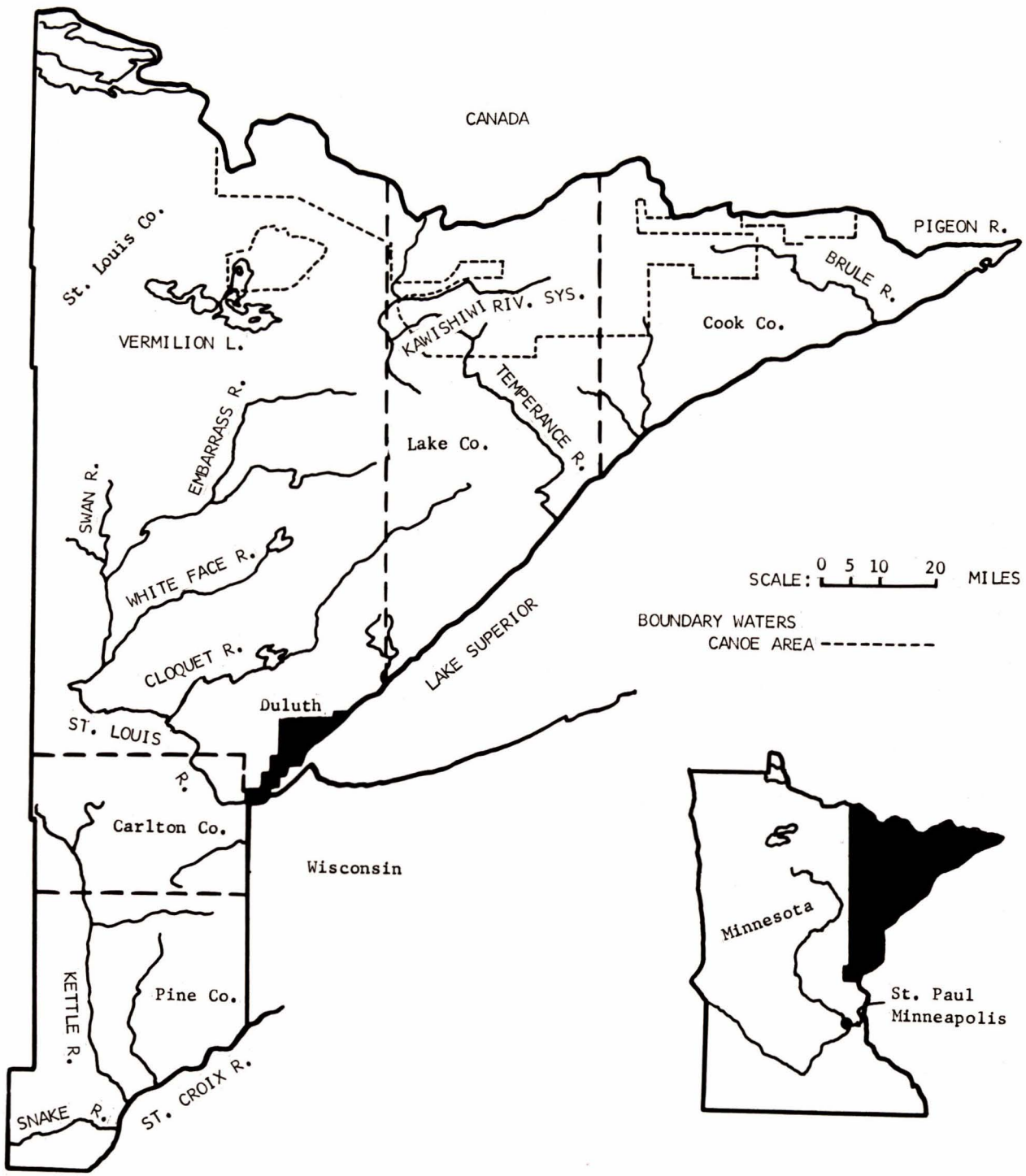


Figure 1.--Location of study area and major streams.

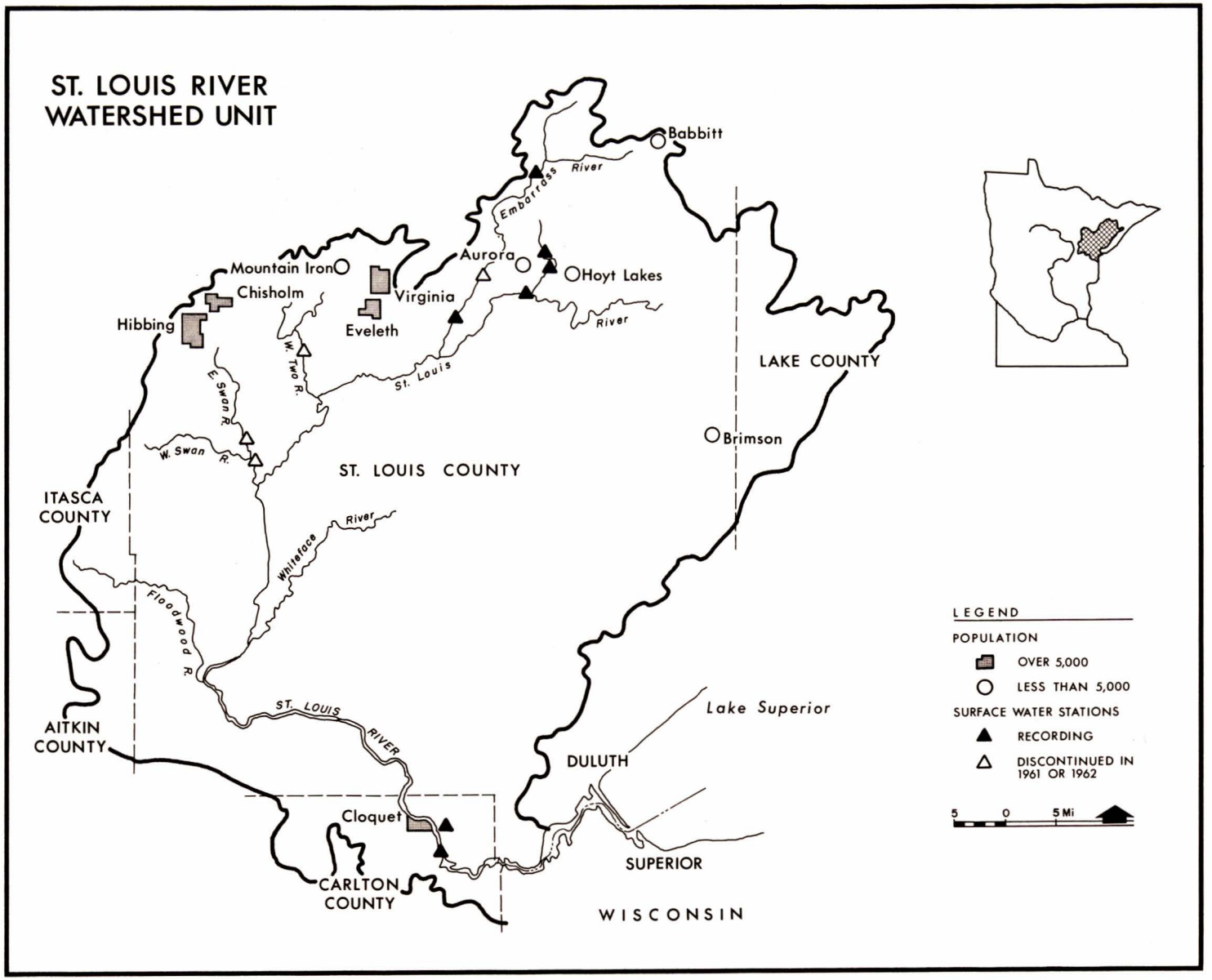


Figure 2.--St. Louis River Watershed Unit.

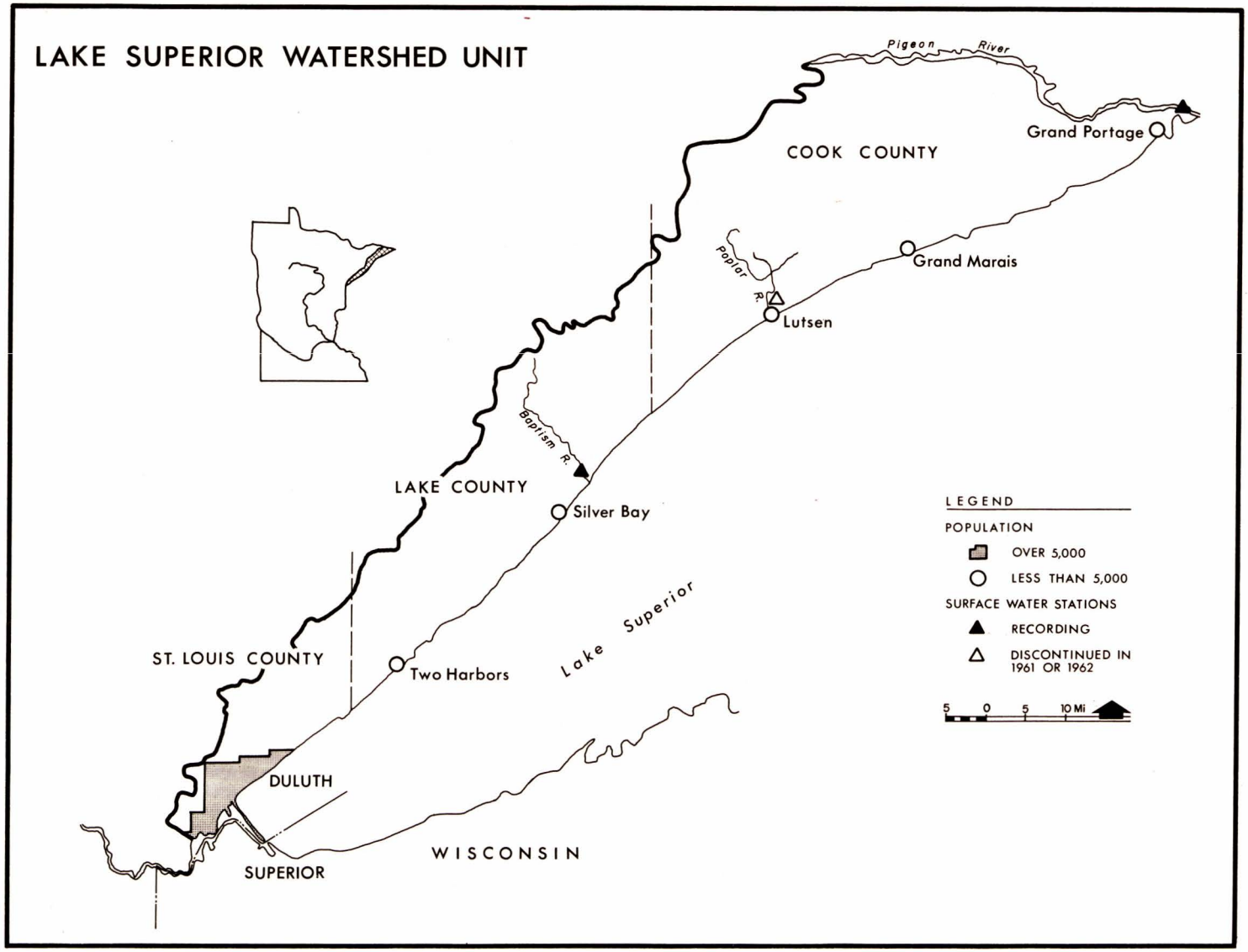


Figure 3.--Lake Superior Watershed Unit.

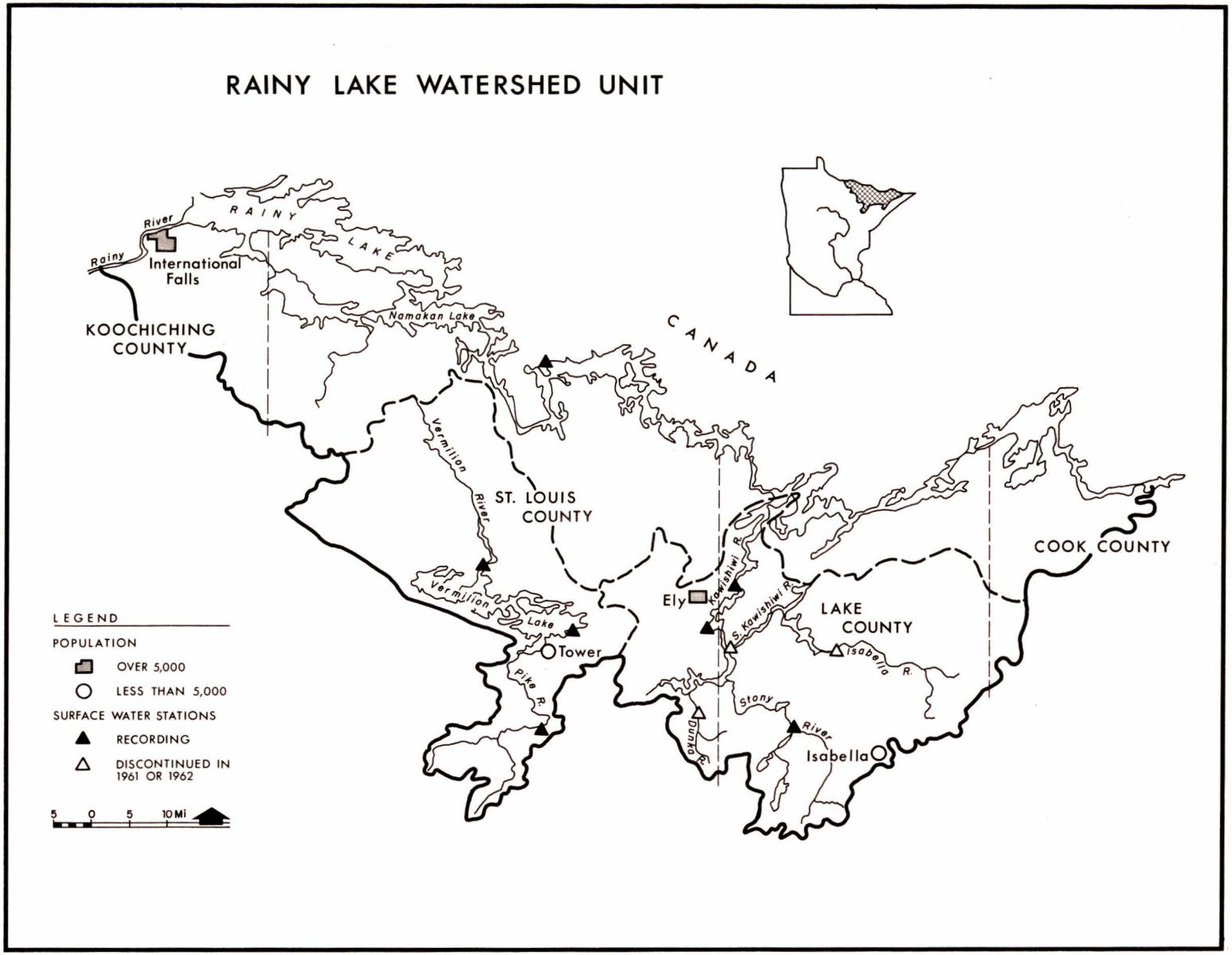


Figure 4.--Rainy Lake Watershed Unit

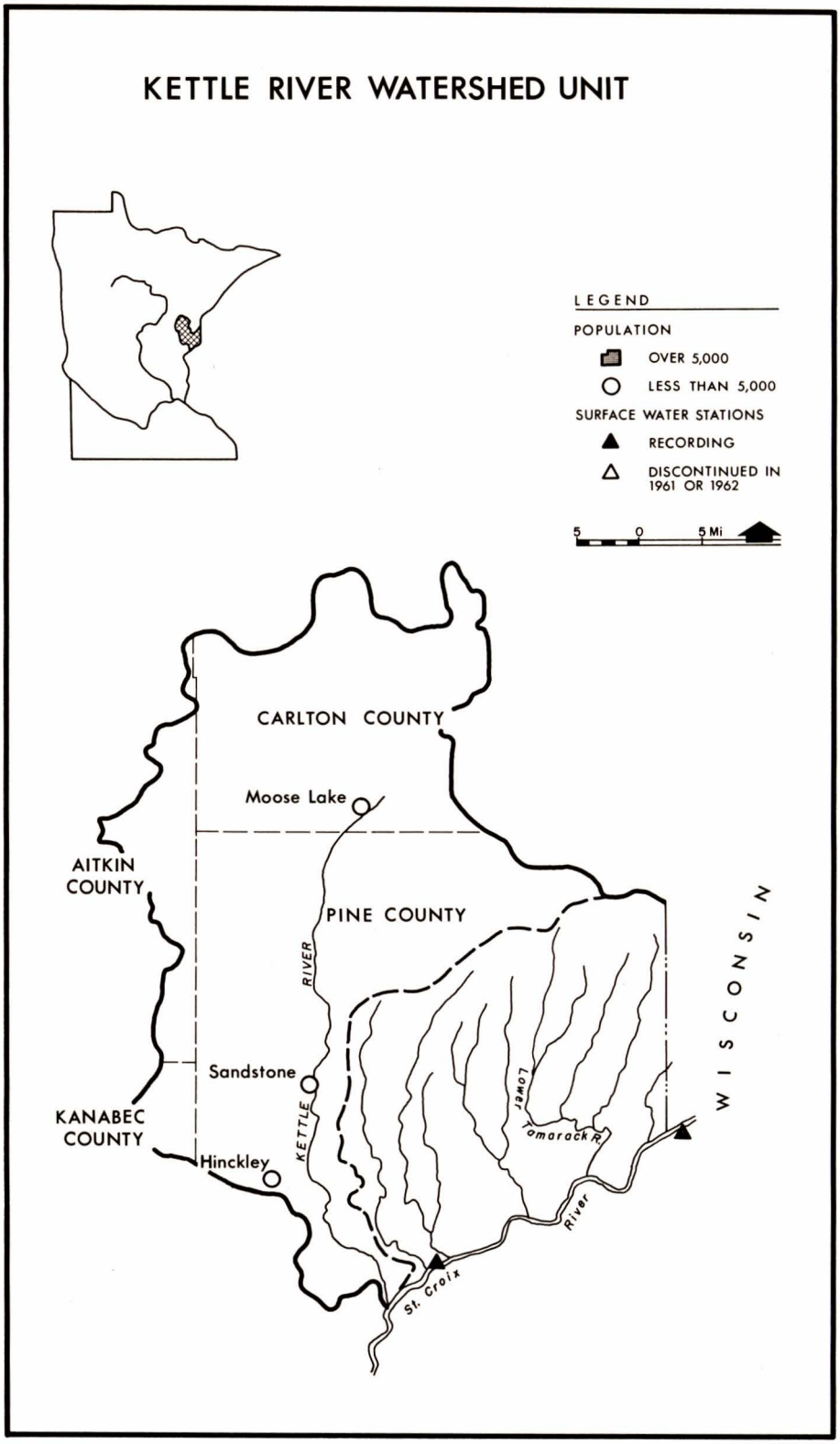


Figure 5.--Kettle River Watershed Unit.

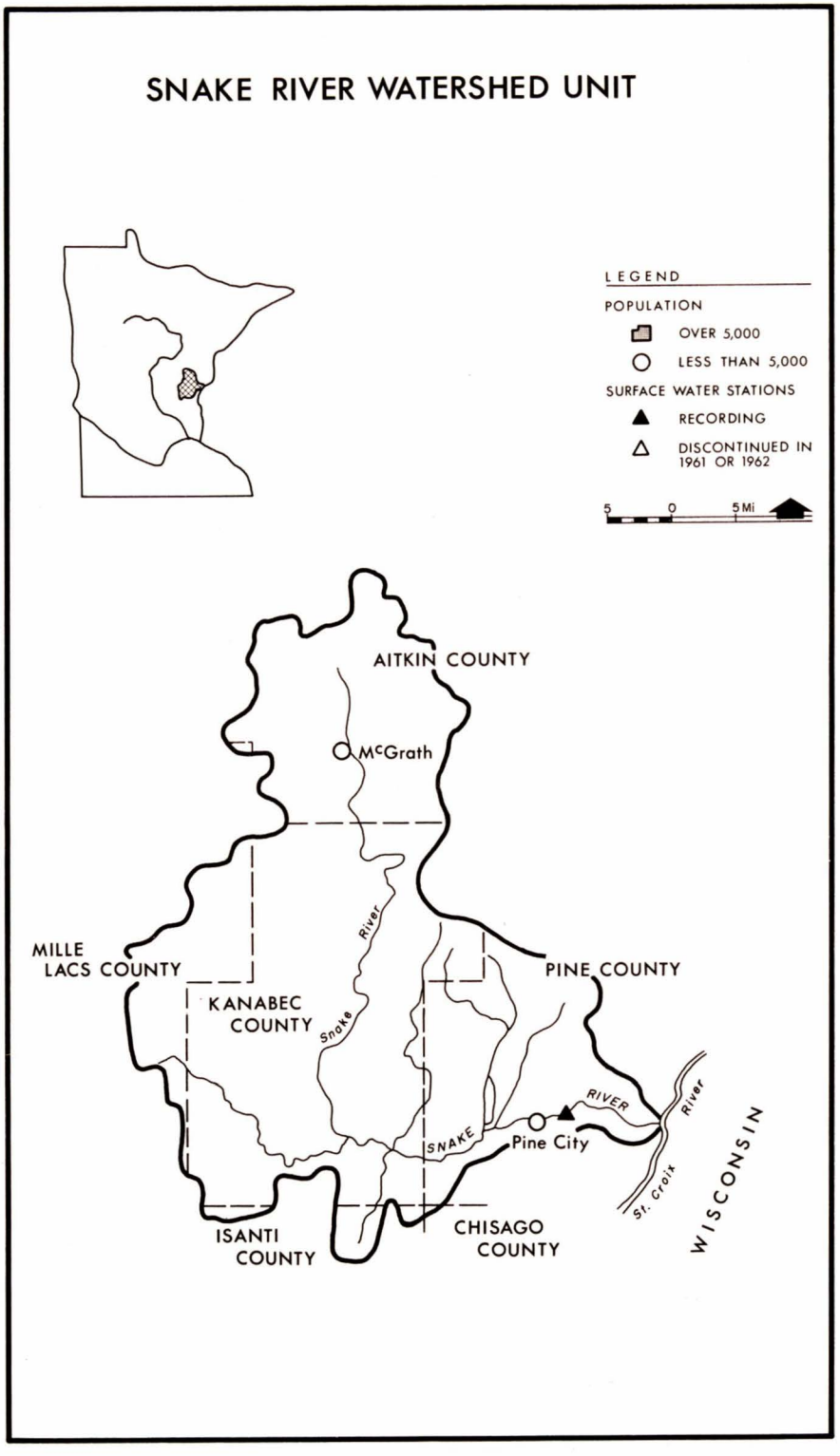


Figure 6.--Snake River Watershed Unit.

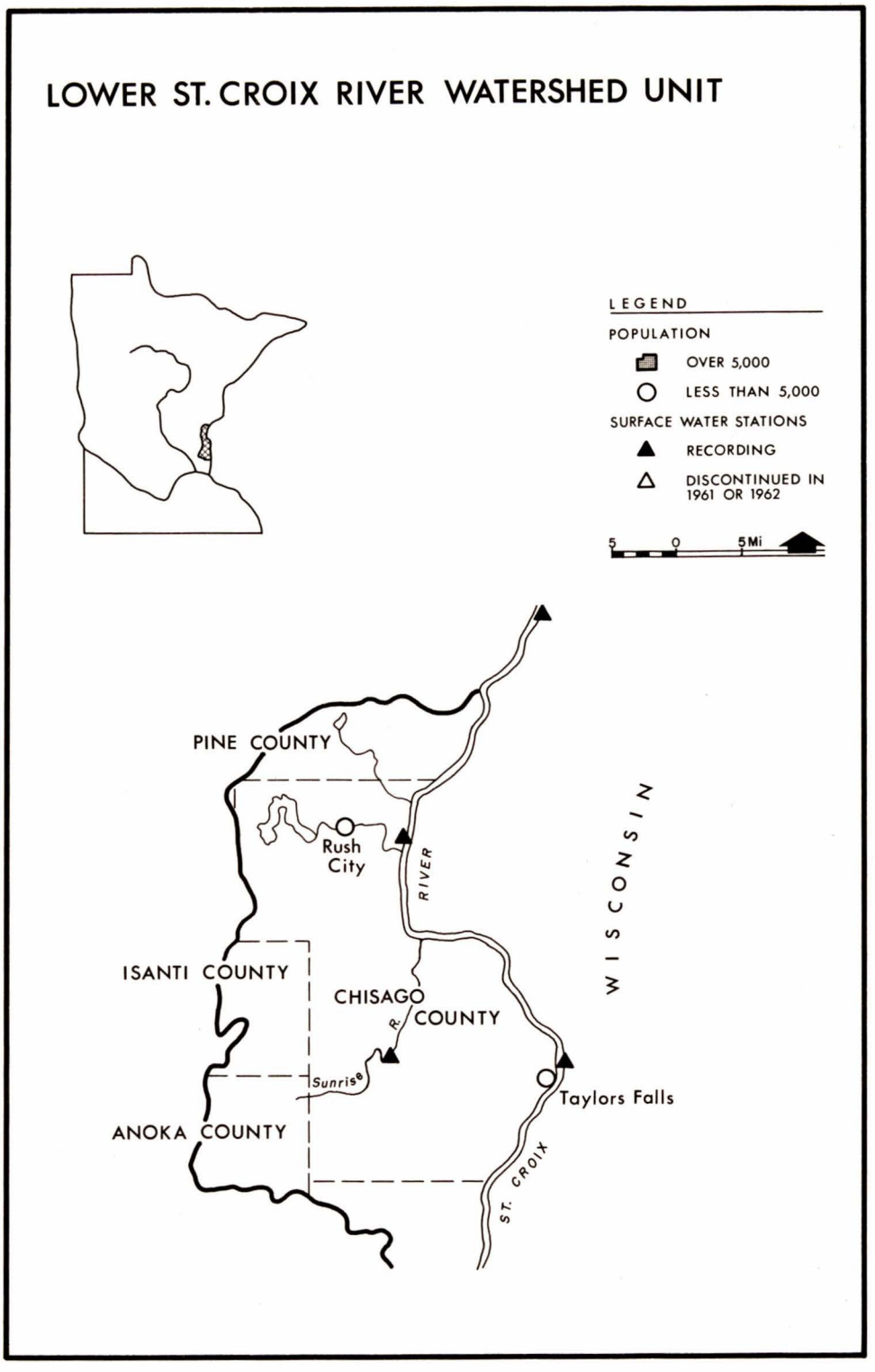


Figure 7.--Lower St. Croix River Watershed Unit.

Figure 8.--Vacationists on Seagull River between Seagull and Saganaga Lakes in Cook County. Recreational use in northeastern Minnesota is increasing substantially every year.

ating plants include Hibbing, Buhl, Chisholm, Virginia, Aurora, Mountain Iron, and Cloquet. Approximately 235 million gallons of Lake Superior water is used daily at the taconite concentrating plant in Silver Bay under permit from the State.

Additional water needs will appear on the Mesabi Range as new taconite beneficiating plants are built. Several industrial firms have indicated interest in building such facilities.

SITE SELECTION

The primary consideration in site selection, as discussed in this paper, is the availability and adequacy of water for manufacturing and dilution of the final treated effluents. The importance of limitations resulting from wilderness establishment, recreational interests, living amenities and labor supplies, transportation, and power facilities is recognized but

Figure 9.--Aerial view of Northwest Paper Company plant at Cloquet.

not stressed. Further examination of other necessary resources and economic data may indicate that some of the locations chosen have decided limitations beyond those considered here.

No attempt is made to determine at each site the maximum plant sizes by type of process which could be supported by the available water resource, for the following reasons: (1) Some other physical, economic, or institutional factor may limit plant capacity. (2) Plant capacity can vary with the degree of in-plant chemical recovery, reuse and recirculation of water, and ponding or lagooning of effluents. And (3) the current trend is toward integrated plants with more than one process involved. Maximum plant capacity would change with each potential integrated system, as each system would have different water requirements.

Lake Sites

All lakes of 20,000 acres or more outside the Boundary Waters Canoe Area were considered for their development potential. Four lakes--Superior, Rainy, Vermilion, and Namakan (including Lake Kabetogama)--meet minimum size requirements. But only Lake Superior and Vermilion appear to have commercial potential.

No significant developments in the area of Rainy Lake, Lake Kabetogama, and Namakan Lake are likely. The area is sparsely settled, with the closest rail line 10 miles distant from Lake Kabetogama and even farther from Rainy and Namakan Lakes. Power sources are not developed, and recreational users very likely would object to new industrial enterprises. Existing pulp and paper plants at Fort Francis, Ontario, and International Falls (in Koochiching County adjacent to St. Louis County) draw most of their process water from Rainy River near the mouth of Rainy Lake. Location of a new mill on Rainy Lake would cause coloration and turbidity of water in Rainy River and probably result in excessive costs for existing industry in upgrading water to a suitable level for use in manufacture of high-grade papers.

Lake Superior is the most attractive source of water for forest industry expansion in the Arrowhead area (fig. 10). It has one-fourth of the world's fresh water supply and contains more water than all the other Great Lakes combined.[6/] According to the head of a Duluth consulting engineering firm, use of Lake Superior water could increase a thousandfold without any harmful effects.[6/]

Chemical and physical analyses of Lake Superior water[7/] indicate that quality is excellent for pulp and paper production when compared with the average raw water analyses in table 2 and the specifications in table 3. Water in the inner harbor area of Duluth, although less desirable than that from other areas of the Lake, appears to be satisfactory for many processing needs. Generally throughout the Lake, silica and total solid content are relatively low.

Under existing conditions of low use and with adequate precautions against localized pollution, any size plant utilizing any pulp or composition-board process could be built on Lake Superior. If oxygen depletion became a serious problem, which is unlikely from effluent discharges on the North Shore, it probably would occur under ice cover in late winter when replenishment of oxygen in the water is impossible because of heavy snow and ice cover. During the summer dissolved oxygen levels of 8 ppm or higher can be expected in all north shore areas of the Lake except for the inner harbor area of Duluth. In some locations along the north shore saturated or supersaturated dissolved oxygen conditions exist. Considerations relating to discoloration and addition of nutrients to the lake waters could be of more concern than dissolved oxygen problems.

Sites at or near Duluth or Two Harbors have rail and power facilities, plentiful labor supplies nearby, and harbors that can accommodate ocean vessels (fig. 11). No rail lines are on the north shore beyond Two Harbors.

6/ Published statement in North Star News, Minnesota Department of Business Development, January 1963.

7/ See end of report for a list of tables of water analyses that are available at the Lake States Station upon request.

Figure 10.--Lake Superior offers the best opportunities for forest industry expansion with large volumes of high-quality water. (Photo courtesy of Minnesota Department of Business Development.)

No rail lines are on the north shore beyond Two Harbors.

Lake Vermilion covers an area of 49,110 acres in north-central St. Louis County. A suitable mill site on Vermilion would be in the Tower-Soudan area, which is served by Highway 169 and the Duluth, Missabe, and Iron Range Railway (D.M. & I.R.). Electricity is provided by Minnesota Power and Light Company. Labor would be available from Virginia and Ely--nearby communities with substantial available manpower.

Water quality is satisfactory for forest industry use as shown by recent chemical analyses of the Lake. Manganese was not present in the water, but the iron content was at the maximum level for soda and sulfate pulps. The concentrations of most other ions were lower than the median values shown in table 2. Minimum economic-size mills for any composition-board or pulping process, except sulfite, could be built, with adequate

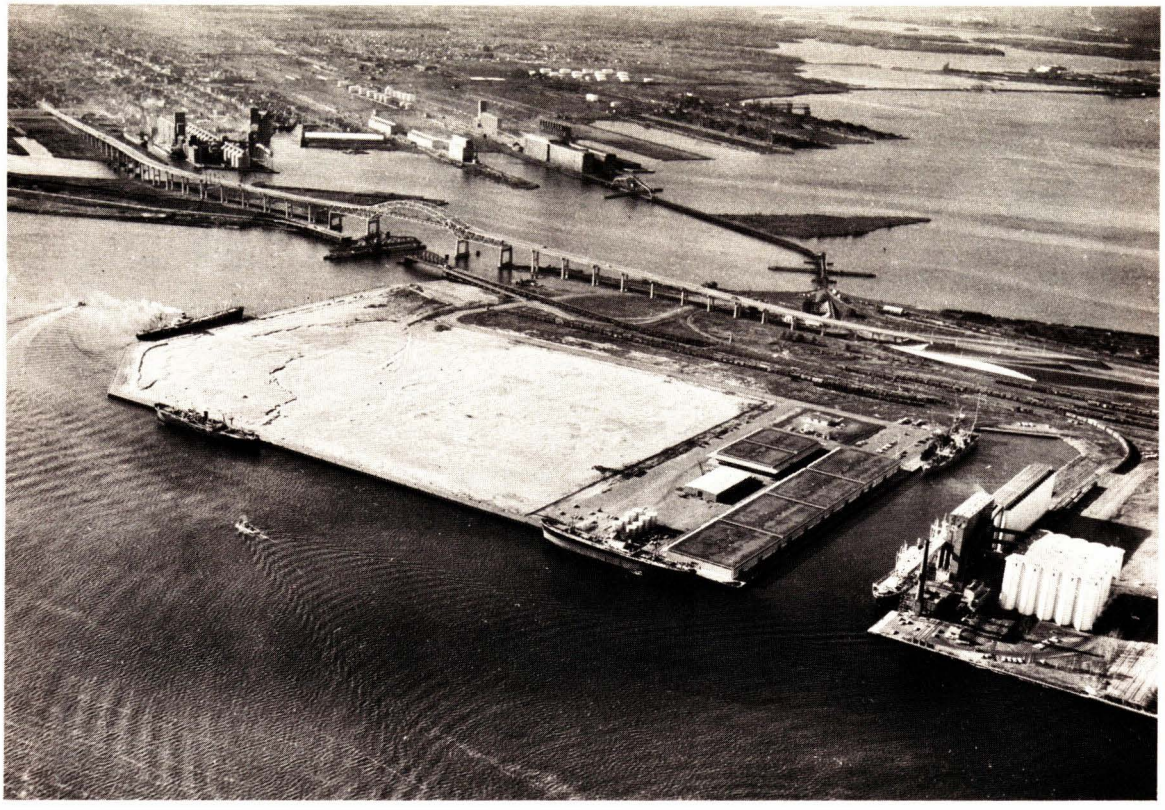


Figure 11.--The Arthur M. Clure Public Marine Terminal at Duluth has excellent facilities for handling intra-lake or overseas forest products shipments. (Photo courtesy Duluth Herald and News Tribune.)

provisions for pollution control. Oxygen depletion danger would be greatest during the winter as in Lake Superior.

Objections from recreation interests around Lake Vermilion to plant development are likely, and such opposition should be assessed early in the planning of any plant development.

Other smaller lakes may be suitable for process water needs, but were not considered in this study. Most remote lakes lack transportation, power, and other necessities. Only a few tests have been made on water quality in smaller lakes, but these indicate that a supply of good process water is available in lakes other than Superior and Vermilion, although treatment for excess iron and manganese may be necessary. The concentration of these two elements is highly variable from lake to lake.

Lakes can be set aside for a single use by the Minnesota Department of Conservation. However, it is usually necessary to buy all shoreline property or property rights. Such lakes might be used as lagoons or settling basins for mill effluents. Plans for such use as part of a waste disposal system must also be approved by the Water Pollution Control

Commission. The Commission, as well as the Conservation Department, considers each lake or development possibility on its own merits.

River Sites

Historic 7-day minimum streamflows are shown in table 5 for all streams that could provide the minimum 14 cfs of process water required by a 150-ton bleached sulfate plant and that have U.S. Geological Survey gaging stations. All other minimum-size plants require less water (table 1). Six of

Table 5.--Historic minimum streamflow data (7 consecutive days) Northeastern Minnesota 1/

Gaging station	Township and range	Min. 7-day discharge (Cfs)	Month and year of min. flow	Years of available data
Pigeon River	64-6	42	Sept.1931	1923-1960
Embarrass River	57-16	14	Sept.1955	1953-1960
Swan River	55-20	20	Jan. 1957	1952-1960
St. Louis River	49-16	2/ 249	Feb. 1924	1908-1960
Isabella River	61-9	36	Feb. 1961	1952-1960
S. Kawishiwi River	62-11	41	Oct. 1960	1951-1960
Basswood River	65-10	84	Dec. 1948	1924-1928 1930-1960
Namakan River	Canada	(3/)	Mar. 1924	1921-1960
St. Croix River	42-15	417	Aug. 1934	1914-1960
St. Croix River	40-18	549	Aug. 1934	1923-1960
St. Croix River	37-20	726	Aug. 1933	1923-1960
Snake River	39-21	42	Feb. 1959	1913-1917 1951-1960
Kawishiwi River	63-11	(4/)	-	1905-1907 1912-1919 1923-1960

Source: U. S. Geological Survey Water Supply Papers 1905-1960.

1/ Includes Carlton, Cook, Lake, Pine, and St. Louis Counties.
2/ Low monthly average February 1924.
3/ Not available, although March 1924 is known to be the month of the minimum flow.
4/ Flow is regulated.

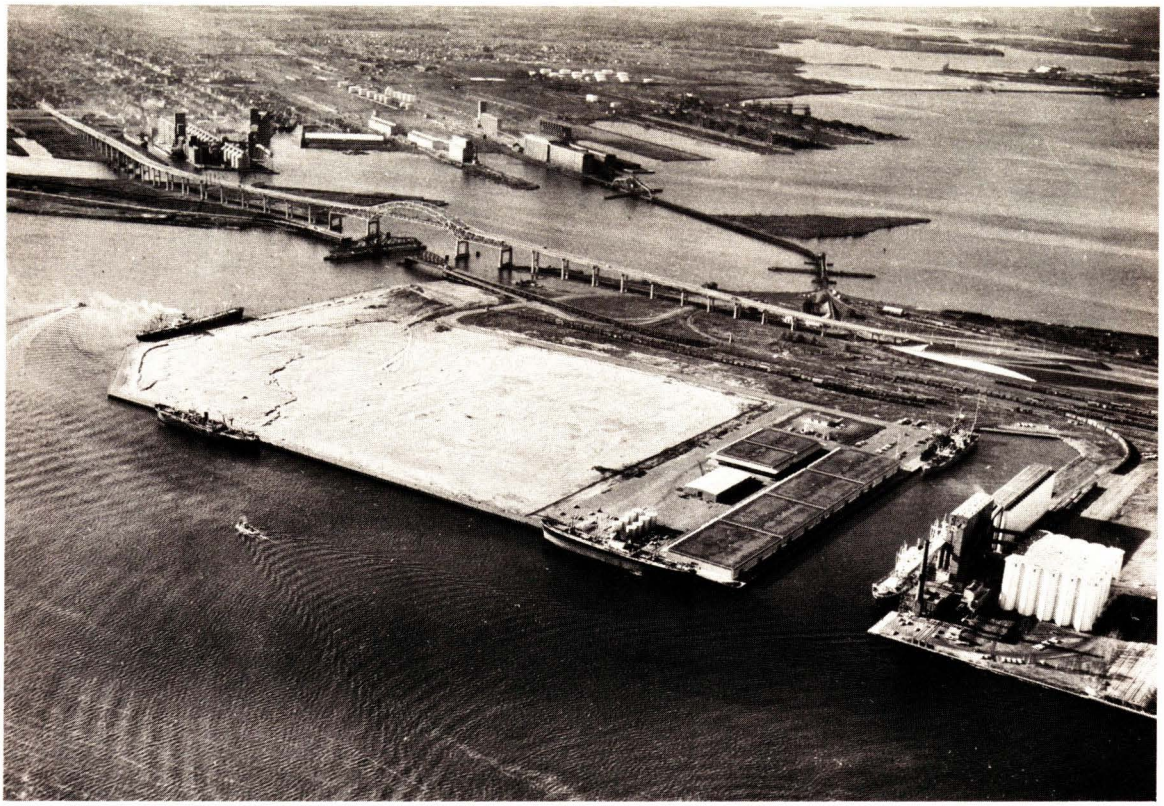


Figure 11.--The Arthur M. Clure Public Marine Terminal at Duluth has excellent facilities for handling intra-lake or overseas forest products shipments. (Photo courtesy Duluth Herald and News Tribune.)

provisions for pollution control. Oxygen depletion danger would be greatest during the winter as in Lake Superior.

Objections from recreation interests around Lake Vermilion to plant development are likely, and such opposition should be assessed early in the planning of any plant development.

Other smaller lakes may be suitable for process water needs, but were not considered in this study. Most remote lakes lack transportation, power, and other necessities. Only a few tests have been made on water quality in smaller lakes, but these indicate that a supply of good process water is available in lakes other than Superior and Vermilion, although treatment for excess iron and manganese may be necessary. The concentration of these two elements is highly variable from lake to lake.

Lakes can be set aside for a single use by the Minnesota Department of Conservation. However, it is usually necessary to buy all shoreline property or property rights. Such lakes might be used as lagoons or settling basins for mill effluents. Plans for such use as part of a waste disposal system must also be approved by the Water Pollution Control

Commission. The Commission, as well as the Conservation Department, considers each lake or development possibility on its own merits.

River Sites

Historic 7-day minimum streamflows are shown in table 5 for all streams that could provide the minimum 14 cfs of process water required by a 150-ton bleached sulfate plant and that have U.S. Geological Survey gaging stations. All other minimum-size plants require less water (table 1). Six of

Table 5.--Historic minimum streamflow data (7 consecutive days) Northeastern Minnesota 1/

Gaging station	Township and range	Min. 7-day discharge (Cfs)	Month and year of min. flow	Years of available data
Pigeon River	64-6	42	Sept.1931	1923-1960
Embarrass River	57-16	14	Sept.1955	1953-1960
Swan River	55-20	20	Jan. 1957	1952-1960
St. Louis River	49-16	2/ 249	Feb. 1924	1908-1960
Isabella River	61-9	36	Feb. 1961	1952-1960
S. Kawishiwi River	62-11	41	Oct. 1960	1951-1960
Basswood River	65-10	84	Dec. 1948	1924-1928 1930-1960
Namakan River	Canada	(3/)	Mar. 1924	1921-1960
St. Croix River	42-15	417	Aug. 1934	1914-1960
St. Croix River	40-18	549	Aug. 1934	1923-1960
St. Croix River	37-20	726	Aug. 1933	1923-1960
Snake River	39-21	42	Feb. 1959	1913-1917 1951-1960
Kawishiwi River	63-11	(4/)	-	1905-1907 1912-1919 1923-1960

Source: U. S. Geological Survey Water Supply Papers 1905-1960.

1/ Includes Carlton, Cook, Lake, Pine, and St. Louis Counties.
2/ Low monthly average February 1924.
3/ Not available, although March 1924 is known to be the month of the minimum flow.
4/ Flow is regulated.

the 13 locations have been eliminated from consideration for reasons other than water availability. For instance, the Pigeon River site is close to Lake Superior (a more favorable water source) and has no rail transportation. The Basswood, Namakan, and Isabella River districts are in the Boundary Waters Canoe Area where use is restricted by law. The other possibilities eliminated were on the St. Croix River near Danbury, Wis., and near Grantsburg, Wis. Each is less favorably situated than the Rush City, Minn. location (T37N, R20W) with respect to available water volume, labor supplies, and transportation facilities.

Locations of the gaging stations (fig. 12) for the seven remaining sites are as follows:

River	Location of gaging stations
South Kawishiwi	10 miles SE of Ely
Kawishiwi	5 miles E of Ely
Embarrass	8 miles SE of Virginia
Swan	12 miles SE of Hibbing
St. Louis	3 miles SE of Cloquet
Snake	1½ miles NE of Pine City
St. Croix	5 miles E of Rush City

For each river, table 6 summarizes available data on summer dissolved oxygen levels, water temperatures, and 7-day minimum flows. The critical month for pollution danger in the rivers is usually August, when dissolved oxygen levels are lowest. The 1942 statistics for the Embarrass and Swan Rivers should be valid indicators of present conditions as no apparent changes have occurred along these streams. Table 7 contains 7-day minimum flows expected at recurring intervals for four of the rivers; data on expected minimum recurring flows for other streams are not available. For example, at the South Kawishiwi River near Ely, the lowest average flow expected for 7 consecutive days during the next 10 years is 58 cfs (37.5 million gallons/day); during the next 20 years, the low anticipated for a 7-day period is 39 cfs (25.2 million gallons/day). The 7-day minimums are based upon past flow records and statistical probabilities of their recurrence. Each of the seven sites (figs. 13 to 16) is assessed below for development potential; the locations discussed could be any sites near the gaging stations that appear suitable and provide sufficient volumes of water.

ANALYSIS OF SPECIFIC RIVER SITES

St. Croix River

The St. Croix (fig. 13) is the only river in the five-county area (not already intensively used) that would have the water necessary to support the "yardstick" 150-ton bleached sulfate mill. For this mill, requir-

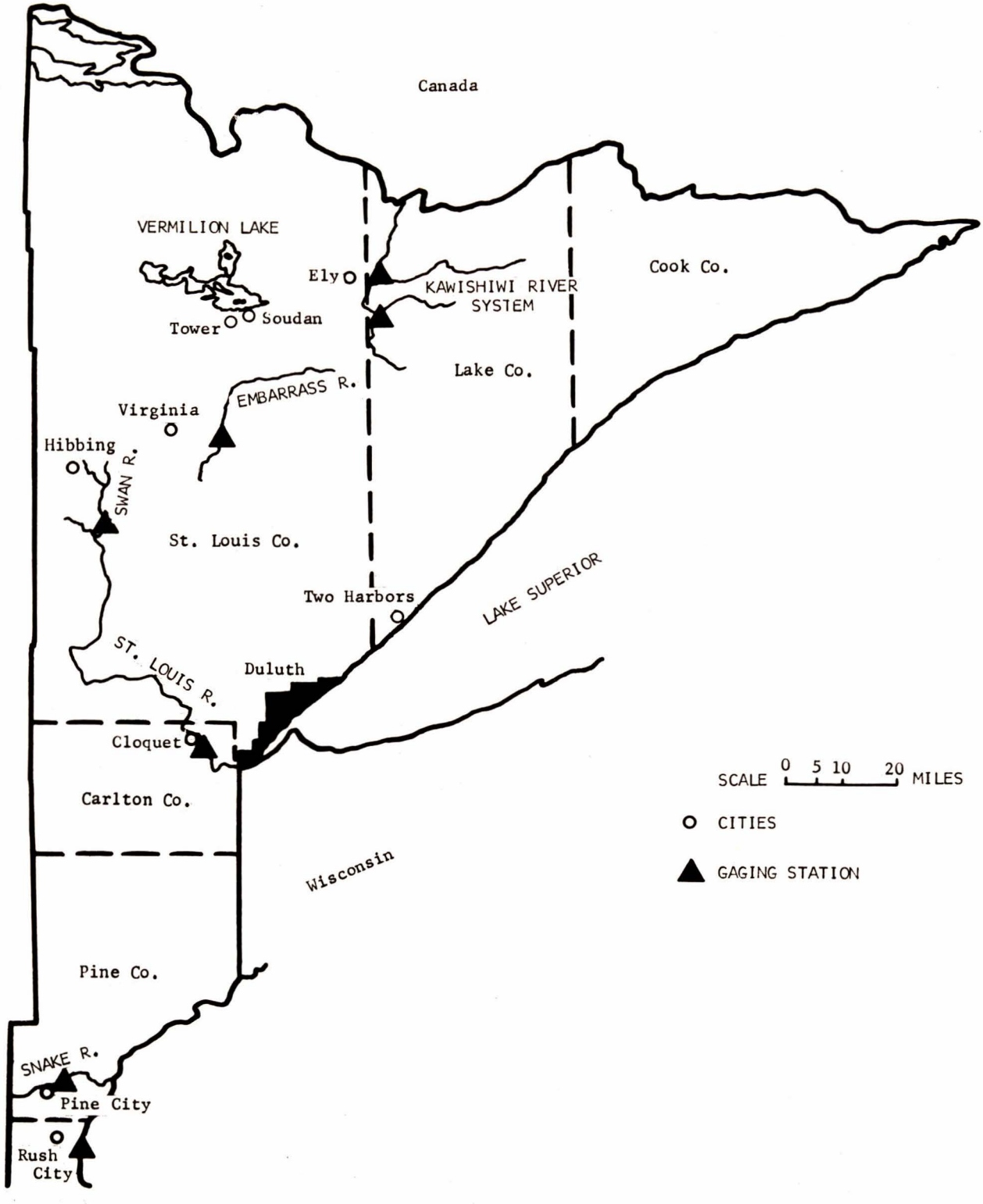


Figure 12.--Locations of gaging stations and sites analyzed.

Table 6.--Analyses of northeast Minnesota streams for determination of safe pollution loads

River	Date of chemical analyses	Diss. O_2	Temp. F°	7-day minimum flow (cfs) August 1951-60	7-day minimum flow (cfs) Year round 1951-60	7-day minimum flow (cfs) Historic minimum	Years of flow records
St. Louis	8-22-58	2.1	68	592	530	249	1908-1960
St. Louis	6-3-59	5.7	57	-	-	-	-
St. Croix	7-16-58	5.8	68	1,483	1,400	726	1923-1960
St. Croix	6-3-59	5.3	65	-	-	-	-
Embarrass	Summer 1942	7.5	66	20	14	14	1953-1960
Embarrass	Summer 1942	8.2	68	-	-	-	-
Swan	NA[1/]	NA	NA	28	20	20	1952-1960
S. Kawishiwi	NA	NA	NA	98	41	41	1951-1960
Snake	NA	NA	NA	34	42	42	1913-1917 1951-1960
Kawishiwi	NA	NA	NA	223	97	NA	1905-1907 1912-1919 1923-1960

Sources: Section of Water Pollution Control, Minnesota Dept. of Health; Division of Game and Fish, Minnesota Dept. of Conservation; U. S. Geological Survey.

1/ NA = data not available.

Table 7.--Expected 7-day minimum streamflow on nonregulated streams[1/]

Gaging station	Drainage area, sq.miles	Discharge in cfs for recurrence intervals shown: 2 years	10 years	20 years	30 years
S. Kawishiwi R. (near Ely)	240	110	58	39	30
Embarrass R. (Virginia)	171	20	15	12	-
Swan R. (Hibbing)	254	29	15	-	-
St. Croix R. (Rush City)	5,120	1,339	941	842	814

Source: U. S. Geological Survey (data on other sites not available).

1/ Nonregulated streams are not controlled or affected by reservoirs or impoundments.

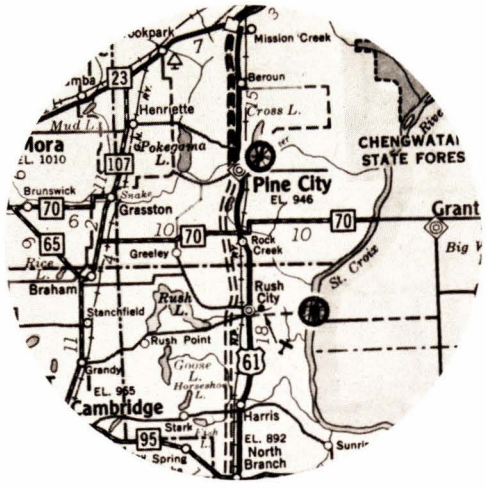


Figure 13.--St. Croix and Snake River Sites

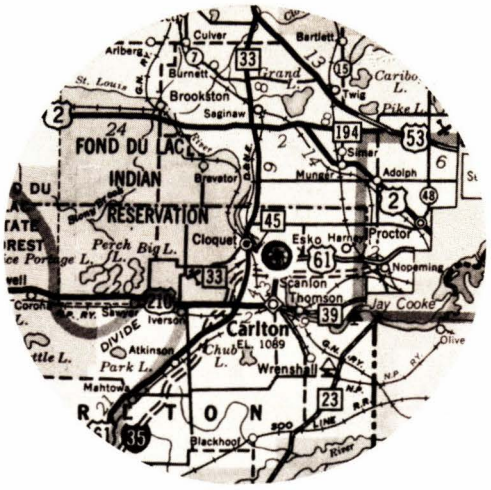


Figure 14.--St. Louis River Site

Figure 15. --Kawishiwi and South Kawishiwi River Sites

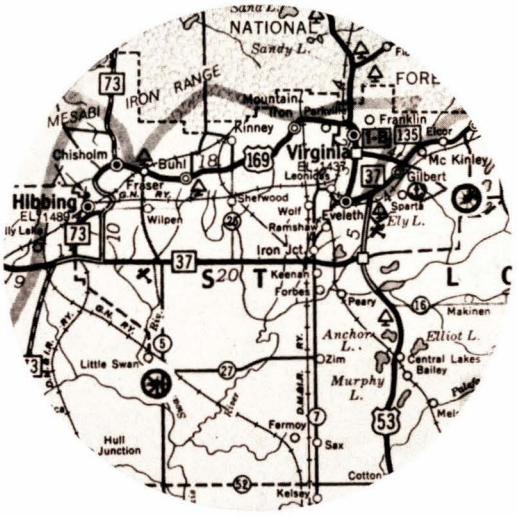


Figure 16. --Embarrass and Swan River Sites

Scale: 1 inch = 12 miles

Figures 13-16.--Locations of seven river sites. The heavy black circles indicate gaging station locations.

ing at least 9 million gallons of process water per day,[8/] the river should readily assimilate the treated effluent.

The site near Rush City (population 1,108) is only 12 miles southeast of Pine City (fig. 17). Both towns have secondary sewage treatment facilities and obtain their municipal water from aquifers. No cities within 30 miles downstream use the St. Croix as a water source. St. Paul is considering the river as a future supplementary water source, however, with a possible intake to be located between Stillwater and Marine-on-St. Croix.

Figure 17.--Attractive level mill sites are found along the St. Croix River near Pine City and Rush City. Recreationists may oppose development along the river.

The area is relatively undeveloped, a quality which has made the St. Croix attractive for leisure-time activities. Recreation along the river is an important use and is increasing as Minneapolis-St. Paul residents find the area appealing. Opposition to manufacturing plants by recreationists could be a limiting factor.

8/ The lowest historical 7-day discharge on the St. Croix near Rush City was 726 cfs (469.2 million gallons/day) in August 1933. From 1951-1960 the 7-day low discharge was 1,400 cfs (905 million gallons/day) with an August low during the period of 1,483 cfs. During the summer 5.5-6.0 ppm of dissolved oxygen can be expected with a maximum water temperature of 70° F.

St. Louis River

As mentioned earlier, water from the St. Louis River (fig. 14) is used for the processing requirements of the wood-using industries in Cloquet. Dissolved oxygen content below Cloquet is less than 3 ppm during some periods in late summer, an indication of the intensive industrial use of the river. With low oxygen content in the summer, industrial expansion may be limited; extensive waste treatment facilities and in-plant waste recovery programs would be essential to maintain the summer oxygen levels if additional river water is required. Duluth, only 19 miles from Cloquet, could provide much of the labor resource necessary for expanded wood-using plants.

Kawishiwi River

Groundwood pulp, hardboard, particle board, or insulation board mills could be built along the Kawishiwi River (fig. 15) and maintain 5 ppm of dissolved oxygen in August, assuming a reasonable degree of waste treatment. Other pulping processes would contaminate the stream and probably conflict with recreational use of the river. Even with settling ponds and in-plant recovery systems, the use of these other processes is questionable unless considerable additional waste treatment is provided. Short periods (1 to 3 days) of no flow occur when reservoir storage is built up in the interests of power development. The hydroelectric station at Winton is a potential power source for new industry.

Ely and Winton have secondary sewage treatment facilities, and neither town obtains municipal water from the river. The D.M. & I.R. Railway serves both towns. Highways 169 and 1 are nearby for truck transportation.

Based on recent employment data, an estimated 100 to 150 laborers would be available in the vicinity of Ely for either woods or in-plant work.

South Kawishiwi River

The South Kawishiwi River (fig. 15) and the other three discussed below could furnish water requirements for hardboard, particle board, or insulation board plants and maintain an adequate dissolved oxygen content, again assuming a reasonable degree of waste treatment. Being within 10 miles of the Kawishiwi River site, the South Kawishiwi area has many of the same advantages and disadvantages. Having less available water and poorer access to transportation facilities and utilities, the South Kawishiwi appears to be less attractive than the Kawishiwi River locale.

Snake River

The Snake River (fig. 13), running through northern Pine County, is supplied by numerous lakes and swamps which collect and store runoff and then release it slowly. Except for periods of low flow caused by ice effects, daily flows at Pine City (population 1,972) are usually more than 75 cfs (48.5 million gallons/day). All municipalities in the region with sewer systems are equipped with sewage treatment plants, and no raw sewage is discharged into streams in the watershed. Water resources would be adequate for a fiber board plant.

Pine County has considerable available labor. In May 1963, 406 county residents were registered at the nearest State Employment Office. The region is served by the Northern Pacific Railway and Highway 61. Pine City is only 62 miles from the Minneapolis-St. Paul market center.

Embarrass River

The Embarrass River (fig. 16) could supply the water requirements only for composition board mills without danger of polluting the stream unless a high degree of waste treatment is provided. From 1951-60 the low flow in August was only 20 cfs. A dissolved oxygen level of 6 ppm or more can be expected during the summer. Most nearby communities have secondary sewage treatment plants. Industrial water uses would not affect municipal water supplies. Recreational water use is less intense than in the Ely area.

The site, 8 miles from Virginia (population 14,034) and Eveleth (population 5,721), is near a large local labor force. In October 1962 approximately 800 persons were seeking permanent employment in the State Employment Office in Virginia. Nearby transportation facilities include the D.M. & I.R. Railway and Highways 169 and 53.

Swan River

The Swan, another small river southeast of Hibbing (fig. 16), appears to be capable of supporting only composition board plants without a high degree of waste treatment. From 1951-60 the low 7-day flow in August was 28 cfs (18.1 million gallons/day). Dissolved oxygen levels in August are 7 ppm or more. Both Chisholm and Hibbing have secondary sewage treatment plants.

Hibbing (population 17,731), another city with abundant available labor, is only 12 miles from this location. About 1,180 people had applied for permanent positions in the State Employment Office at Hibbing in October 1962. The local area could probably supply 300-400 woods and mill employees. Proximity to the Great Northern Railway is an important asset of this site. A hard surfaced secondary road connected to Highway 53 is available.

Quality of River Water

Conclusions about water quality at the various river sites just discussed are based upon chemical and physical analyses. With the exception of the St. Louis below Cloquet, water quality appears satisfactory in all rivers for selected processing needs. Although iron content and coloration are high in the Swan, Embarrass, Kawishiwi, and South Kawishiwi Rivers, they are not excessive for composition board products. The Swan has relatively hard water and may require some treatment.

Additional testing may be necessary for all streams. The St. Croix River, for example, has adequate water for producing high-quality pulp, but some treatment for excess coloration may be essential.

GROUND WATER SUPPLY AND QUALITY

Many municipalities obtain their water from wells (see table 4 for approximate daily use). The larger supplies of ground water are found in glacial drift or the Biwabik Iron Formation. The supply is variable and any ground water developments should be preceded by test drilling and controlled test pumping.

In the St. Louis River Watershed, glacial drift is usually a favorable source of ground water, with a few local exceptions. Also, ore deposits of the Biwabik Iron Formation (located in central St. Louis County near communities such as Hibbing, Buhl, Virginia, Eveleth, Biwabik, and Aurora) are capable of sustaining high yields of ground water. As a source of industrial water supply in the past, the ore-deposit aquifers have been suitable and readily accessible, except in some areas where expanded mining operations disrupted water supplies.

In the Mountain Iron-Virginia region of the St. Louis River Watershed, the U.S. Geological Survey has found that in coarse outwash deposits, well yields of approximately several hundred gpm (gallons per minute) can easily be obtained; and, with proper construction, screen-size selection, and development, yields on the order of 2,000 gpm are possible. It is estimated that in this area about 5 square miles are underlain by 30 to 120 feet of saturated, permeable sand or gravel. These deposits are the most favorable for ground water development.

In the Lake Superior Watershed Unit, well records indicate that relatively few water supplies are obtained from glacial drift and that lava flows, although undependable, are the best source in the bedrock. The success of any well, based on the present state of knowledge, appears to be unpredictable.

The only areas of the Rainy Lake Watershed Unit with appreciable quan-

tities of ground water in the glacial drift are in the upper parts of the Pike, Stony, and Isabella River Basins. The sandy character of the glacial outwash indicates that large yields are possible in the areas where the saturated zone is sufficiently thick. On the southwest side of Birch Lake a glacial outwash aquifer up to 70 feet thick has been developed as a water supply for the village of Babbitt. One of three wells in the aquifer has been tested at a pumping rate in excess of 1,000 gpm. Similar aquifers may exist in the other areas mentioned. Ground water in the bedrock is restricted to joints, fractures, and fissures. Bedrock wells have produced sporadic results; some wells have adequate yields, others are dry holes.

Satisfactory water supplies in the Kettle River Watershed can be obtained from sand and gravel lenses in thick and permeable glacial drift. Where drift cover is thin in northern and southeastern parts of the watershed, ground water supplies are inadequate and development of bedrock aquifers is necessary.

Ground water in the Snake River Watershed Unit occurs most abundantly in Pre-Cambrian sandstone and glacial drift. In glacial drift it is available in varying quantities, depending on the general character of the drift and the size and thickness of enclosed sand and gravel lenses. Where the drift is neither thick nor permeable, wells are drilled into bedrock. In the northern, northwestern, and extreme eastern part of the watershed, ground water in the bedrock is restricted to fissures and fractures. In the lower part of the watershed west of Pine City, ground water in the Hinckley sandstone occurs in the pore spaces as well as in fractures and fissures. The Hinckley sandstone is much more favorable for developing water supplies than is the basaltic or granitic rock. Generally water levels range from 5 to 25 feet below the land surface.

The ground water in the Mesabi Range area has large variations in chemical constituents between wells. Before using as process water, treatment for one or more of the following excesses may be necessary: silica as SiO_2, iron, manganese, hardness as $CaCO_3$, alkalinity as $CaCO_3$, dissolved solids, and color. Limited quality testing near Cloquet shows that iron and hardness are sometimes superabundant.

With water quality and volume varying from well to well, no industrial use of ground water should be contemplated until test drilling, controlled test pumping, and chemical analyses have been made.

A POTENTIAL WATER SOURCE

A water pipeline from Duluth to Cloquet has been proposed to tap Lake Superior water. Estimates of the pipeline size range from 36 to 48 inches and of water capacity per day from 20 to 40 million gallons. Wood-using firms in Cloquet would benefit greatly from this additional source of water. New industries could locate along the pipeline outside Duluth where open areas,

transportation facilities, and electric utilities are available.

STATE REGULATIONS

Water Appropriation

Appropriation of water for industrial use must be approved by the Commissioner of Conservation or his representative, the Director of the Division of Waters. Each application is considered on its own merits. Pertinent information required includes description of the area of use, the water source, method of taking water, purpose of use, and the estimated time and quantity needed. The application must include requirements for surface and ground water.

Pollution Control

Minnesota has a Water Pollution Control Commission composed of the Secretary and Executive Officer of the State Board of Health, the Commissioner of Conservation, the Commissioner of Agriculture, the Secretary and Executive Officer of the State Livestock Sanitary Board, and three members at large who are appointed by the Governor. Some of the powers and duties of the Commission are (Minnesota Statutes 1961, Section 115.01 - 115.09):

> To administer and enforce all laws relating to the pollution of any of the waters of the State;
>
> To investigate the extent, character, and effect of the pollution of the waters of this State and to gather data and information necessary or desirable in the administration or enforcement of pollution laws, and to make such classification of the waters of the State as it may deem advisable;
>
> To establish and alter such reasonable pollution standards for any waters of the State in relation to the public use to which they are or may be put as it shall deem necessary for the purposes of sections 115.01 to 115.09 of the State Water Pollution Control Act;
>
> To make and alter reasonable orders requiring the discontinuance of the discharge of sewage, industrial waste or other wastes into any waters of the State resulting in pollution in excess of the applicable pollution standard established;
>
> To require to be submitted and to approve plans for disposal systems or any part thereof and to inspect the construction thereof for compliance with the approved plans thereof;

To issue, continue in effect or deny permits, under such conditions as it may prescribe for the prevention of pollution, for the discharge of sewage, industrial waste, or other wastes, or for the installation or operation of disposal systems or parts thereof;

To revoke or modify any permit issued whenever it is necessary, in the opinion of the Commission, to prevent or abate pollution of any waters of the State.

"Pollution", according to the Pollution Control Act, is the contamination of any waters of the State so as to create a nuisance or render such waters unclean, or noxious, or impure to such a degree that they are actually or potentially harmful or detrimental or injurious to public health, safety or welfare, to domestic, commercial, industrial, or recreational use, or to livestock, wild animals, birds, fish, or other aquatic life.

The State Board of Health, the policy-making organization for the Minnesota Department of Health, has been authorized by law to investigate the extent, character, and effect of the pollution of public waters of the State so far as such pollution affects the public health. In addition, the Board is required to designate, with the approval of the Water Pollution Control Commission, a qualified and experienced sanitary engineer to act as the Commission's executive engineer, and to furnish such other services as the Commission might need in its administration of the State Water Pollution Control Act. The executive engineer is Chief of the Section of Water Pollution Control of the Minnesota Department of Health. The executive engineer and his staff furnish technical advice and recommendations to the Commission.

To avoid costly future changes, firms contemplating industrial use of water should contact the Water Pollution Control Commission or the Section of Water Pollution Control early in their planning to assure that their waste disposal systems will conform with the requirements of the Commission. Plans for proposed sewage disposal and potable water facilities must also be submitted for review by the Department of Health.

SUMMARY

This study was designed to determine potential sites for new or expanding pulp and composition-board plants in five counties of northeastern Minnesota. The primary consideration was the availability of sufficient water of good quality to support a minimum economic-size plant without causing pollution. A major assumption was that mills would practice a reasonable degree of waste treatment. Secondary locational factors influencing selections were the availability of transportation facilities, labor, and utilities; land use restrictions; and possible conflicts of interest with recreational activities. Sites were considered on two lakes and seven rivers.

On the basis of the previously listed criteria, Lake Superior sites in the vicinity of Two Harbors or Duluth would appear to be desirable locations for wood-using industries requiring a substantial quantity of water. Almost any type of plant could be built along the Lake, with adequate provisions to prevent localized pollution. Lake Vermilion could probably support minimum-size mills using any pulping process except sulfite. Objections by recreationists to industrial development on Lake Vermilion are likely.

The St. Croix River near Rush City is the only river location selected (not already intensively used) that has enough water to fulfill the needs of minimum economic-size plants of any type. Recreation use, though, may be a limiting factor to industrial development.

Under existing conditions of use, expansion of pulping facilities at Cloquet, utilizing additional St. Louis River water, are unlikely without additional in-plant chemical recovery systems or considerable treatment of effluents. Below Cloquet the dissolved oxygen content in the river is less than 3 parts per million during some periods in late summer. A proposed pipeline carrying water from Lake Superior near Duluth to Cloquet would enhance the possibilities for expansion of wood-using firms at Cloquet.

The Kawishiwi River near Ely could supply water for groundwood pulp, hardboard, particle board, or insulation board mills. The remaining rivers--the South Kawishiwi River near Ely, the Snake River near Pine City, the Embarrass River near Virginia and the Swan River near Hibbing--would be suitable as locations for composition board plants.

Water quality at all the locations discussed above except the St. Louis River below Cloquet appears satisfactory for most processing needs. At some locations treatment for excessive iron, coloration, and hardness may be necessary for the manufacture of higher quality pulps.

Localities with favorable ground water resources were not isolated. Ground water varies greatly from well to well in both volume and quality in northeastern Minnesota. Extensive test drilling would be necessary to determine specific sites where ground water is sufficient for manufacturing purposes.

Any companies considering erection of wood-processing plants requiring large volumes of process water in Minnesota, should contact the Water Pollution Control Commission or the Section of Water Pollution Control of the Minnesota Department of Health early in their planning. Waste disposal systems and pollution control measures must be approved by the Commission. In addition, approval of the appropriation of water must be obtained from the Division of Waters of the Minnesota Department of Conservation. Each potential enterprise is considered upon its own merits by the Division of Waters and the Pollution Control Commission.

ADDITIONAL TABLES OF WATER ANALYSES AVAILABLE AT THE LAKE STATES STATION UPON REQUEST

Numerous chemical and physical analyses of the water in Lake Superior and northeastern Minnesota have been prepared by various public agencies. Some of the most pertinent of these, relating to the various site locations discussed in this report, have been assembled by the Lake States Forest Experiment Station and are available upon request.

These analyses are listed below, together with the original sources of the data.

Table no.[1/]	Title and source
8.	Physical and chemical analyses of Lake Superior raw water near Duluth; averages of weekly determinations, 1960. Source: Water, Gas and Sewage Treatment Department, City of Duluth.
9.	Physical and chemical examination of Duluth city water, May 4, 1962. Source: Water, Gas and Sewage Treatment Department, City of Duluth.
10.	Chemical analyses of surface samples, Lake Superior, 1960. Source: Studies on the productivity and plankton of Lake Superior, by Hugh D. Putnam and Theodore A. Olson, School of Public Health, University of Minnesota, 1961.
11.	Chemical analyses of Lake Superior, Duluth-Superior Harbor area, July 21, 1959. Source: An investigation of nutrients in western Lake Superior, by Hugh D. Putnam and Theodore A. Olson, School of Public Health, University of Minnesota, 1960.
12.	Chemical analyses of Lake Superior, Duluth-Superior Harbor area, August 4, 1959. Source: An investigation of nutrients in western Lake Superior, by Hugh D. Putnam and Theodore A. Olson, School of Public Health, University of Minnesota, 1960.
13.	Chemical analyses of Lake Superior, Duluth-Superior Harbor area, August 26, 1959. Source: An investigation of nutrients in western Lake Superior, by Hugh D. Putnam and Theodore A. Olson, School of Public Health, University of Minnesota, 1960.

1/ Table numbers shown were assigned by the Station for the convenience of those people ordering copies. The numbers are not the same as may have been given by the source agency.

14. Chemical analyses of Lake Superior Knife River area. Source: An investigation of nutrients in western Lake Superior, by Hugh D. Putnam and Theodore A. Olson. School of Public Health, University of Minnesota, 1960.

15. Chemical analyses of Lake Superior, August 15, 1957, and August 29, 1957. Source: Water movements and temperatures of western Lake Superior, by Orlando R. Ruschmeyer and Theodore A. Olson, School of Public Health, University of Minnesota, p. 51, 1958.

16. Chemical analyses of Lake Superior, Beaver Bay area, 1960. Source: Studies on the productivity and plankton of Lake Superior, by Hugh D. Putnam and Theodore A. Olson, School of Public Health, University of Minnesota, 1961.

17. Chemical analyses of Lake Superior, northeast Minnesota, 1957. Source: Water movement and temperatures of western Lake Superior, by Orlando R. Ruschmeyer and Theodore A. Olson, School of Public Health, University of Minnesota, p. 50, 1958.

18. Chemical-quality data, Vermilion Lake. Source: U.S. Geological Survey.

19. Chemical analyses of five lakes in northeastern Minnesota. Source: U.S. Geological Survey.

20. Chemical analyses of St. Louis River. Source: Water quality sampling program, Minnesota Department of Health, vol. 2, 1958-59, pp. 60-61.

21. Averages and maximums of chemical constituents and physical properties, 1955-1960. Source: U.S. Geological Survey.

22. Chemical analyses of Embarrass River and Swan River. Source: A biological survey and fishery management plan for the streams of the St. Louis River Basin, by John B. Moyle and Walter A. Kenyon. Investigation report, not published, 161 pp., 1947. On file at Minnesota State Historical Building, St. Paul.

23. Chemical-quality data, Kawishiwi River. Source: U.S. Geological Survey.

24. Chemical analyses of water, St. Croix River (25 miles NE Rush City). Source: Water quality sampling program, Minnesota Department of Health, vol. 2, 1958-59, p. 56.

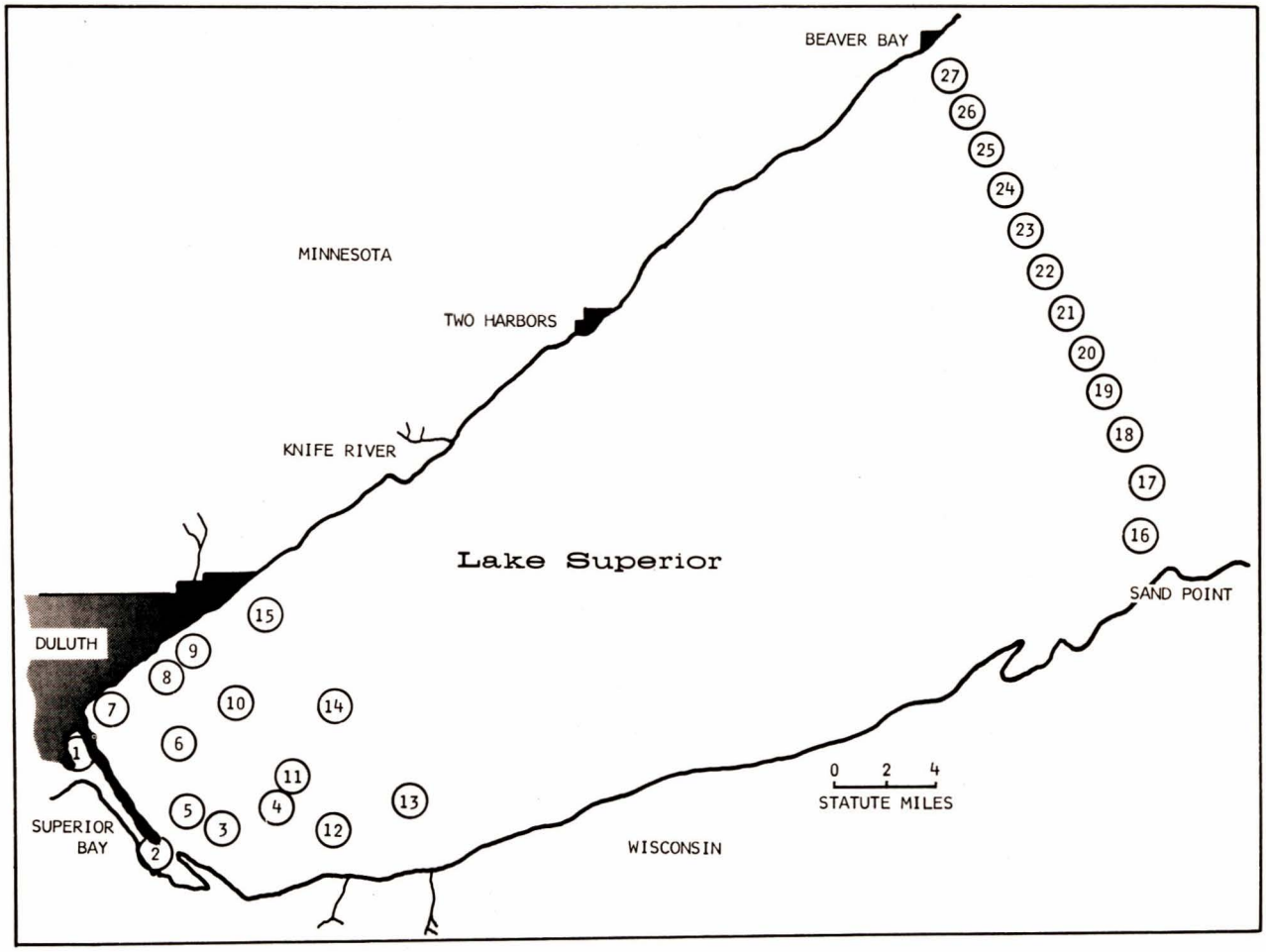
25. Chemical analyses of ground water, Hibbing-Chisholm area. Sources: Data for 10/1/43, Minnesota Dept. of Health and Hibbing Health Dept.; 9/29/54, 1/31/57, 6/12/58, 6/13/58, 9/15/59, and 12/14/60, U.S. Geological Survey; 3/22/57, Hibbing Health Dept.; and an unknown date, Great Northern R.R.

26. Chemical analyses of ground water, Virginia-Mountain Iron area. Source: U.S. Geological Survey.

27. Chemical analyses of ground waters, Cloquet area. Source: U.S. Geological Survey.

28. Chemical composition of ground water used for municipal supply in St. Louis and Itasca Counties. Source: U.S. Geological Survey.

Figure 18.--Location of analysis stations for tables 11, 12, 13, and 15.



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